ORIGINAL RESEARCH ARTICLE

Diagnostic features of *Fraxinus excelsior* L. with wavy-grained wood growing in Ukraine

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Abstract. The paper presents analysis of biometric features of ash with wavy-grained wood, which has decorative appeal. The research results shows that fresh broadleaves ash forest stands growing in the Vinnytsya and Sokyryany Regions of Ukraine have high potential for growing curly ash. The differences between straight-grained and wavy-grained wood density and macrostructure were analysed and estimated. Statistical evaluation of the aesthetic macrostructure of wood characteristics indicated that the length of wave varied from 3,25 to 10,83 mm and its amplitude varied from 0,37 to 1,74 mm. The average width and mean height of anomalies in wood formation were equal to 15,89 mm and 5,00 mm, and their mean occurrence was 30 times m^{-2}. Average annual growth ring width of wavy-grained ash wood was clearly greater (by 25%) than that of straight-grained wood. The density of wavy-grained wood was 82 kg·m^{-3} higher than straight-grained wood after oven-drying and 70 kg·m^{-3} higher prior to oven-drying.

Key words: common ash, wavy-grained wood, biometry, decorative wood, anomaly wood, forest stands

1. Introduction

Common ash is one of the important hardwood trees species in Ukraine and across Europe. At the age of 100 years they are 30 m height and have 60–70 cm in diameter. Their wood texture supplies the simply decorative wood (Gottwald 1989; Schmidt 2002; COST E42 2008; Sopushynskyy 2011). One of the inter specific variability of ash is characterised by special wood anomalies like wave-grain (Fig. 1).

The wavy-grained wood of common ash is characterised by valuable decorative features. Such figures in a wood have been defined as unusual grain or abnormal grain pattern that adds value to solid wood products by aesthetic characteristics (Beals et al. 1977; Bauch 1980; Harris 1989; Bucur 2006; Sopushynskyy et al. 2006). The wave-grained wood of ash displays fine textures which have quite a high decorative value (Chovanec 1986; Gottwald 1989; Wobst 1994; Sopushynskyy 2011).

The quality of decorative wood can be reflected by its utility and therefore is defined by the consumers. Wood quality criteria can only be applied for the specific purpose for which it is used (Harris 1989; Grześkiewicz 2007; Hemery et al. 2008). The main wood characteristics that define the timber quality classes of ash according to the current European norms (Normen über Holz 2009) include average diameter, knots, wood growth, colour, sweep of the wood etc. but do not include the decorative wood characteristics: width and height of anomaly wood formation, its number etc. Thereby, the decorative value of ash wood is important in the context of its classification by quantifiable or explicable charac-

Figure 1. The wavy-grained wood of common ash growing in Ukraine

teristics (Yatsenko-Khmelevskyy 1954; Rioux et al. 2003; Vintoniv et al. 2007; Sopushynskyy 2006, 2012).

The diversification of customers' demands for specific aesthetic wood properties leads to a gain of sawed or cut wood surfaces which supply the fine or decorative appearance of wood products (Mayevskyy et al. 2008). Insufficient knowledge and poor understanding of the high value of broadleaved species with high-quality decorative wood (due to wave-grained wood of ash) leads to a lack of willingness of cultivating these species and also to inconsistent supply of timber with high-value decorative wood.On the other hand there is evidence that the final consumers are ready to pay a higher price for personalised and customised products e.g. furniture, interior design, floors with highly decorative wood surfaces (Furnier Magazin 2008, 2009; Surface Magazin 2008, 2009, 2010; Laminate Magazin 2008, 2009).

The aims of the present study are to assess the biometric and wood macrostructure characteristics of ash trees with wave-grained wood and to determine the distinctions of wood density between straight-grained and wave-grained wood. Also this paper provides a framework fora future research in the subject area of the diagnostic model development of ash trees with wave-grained wood. Furthermore, it provides information for the conservation of ash with high decorative wood.

2. Materials and methods

The study was conducted in the fresh broadleaves ash forest stands growing in theVinnytsya and Sokyryany regions of Ukraine. Silvicultural and dendrometrical characteristics of broadleaves forest stands were collected on three observation plots (OP) of field studies

with focus on acquiring and in-depth understanding of ash with wavy-grained wood as well as its silvicultural potential (Table 1).

Altogether, 11 models of ash trees with wavy-grained wood and 11models of ash trees with straight-grained wood were studied for their biometric and morphological features as well as wood density. The biometric characteristics were collected from the fell model trees. To systematize knowledge about differences in morphological characteristics of curly ash specific features have been used (Fig. 2).

The morphological characteristics of a wood surface and an annual ring width were measured by software AutoCAD 8.0 on the digital photos.The wood density was determined at breast height.The discs were cut into three segments: juvenile wood where heartwood formation may be initiated (years rings 5–20 from the pith), transition heartwood (approximately 10–40 years rings), and sapwood (years rings 20–60 from the bark). The green volume of the segments was measured by water displacement method. By using the oven drying method the oven-dry mass was measured after 24 h at $103 \pm 2^{\circ}$C. The initial weighing of each sample was made as soon as possible after it had been cut and the measurement was made to the nearest 0,001 g on a precision balance. Errors, due to unavoidable delay before weighing, were minimised by placing the sample in polythene bags immediately after cut. Basic wood density was calculated as the ratio of the weight of the oven-dry wood and the volume of green wood; the density of oven-dry wood was calculated as the ratio of the weight and the volume of the oven-dry wood. (Vintoniv et al. 2007).

The statistical analyses was based on procedure SPSS 13.0 – One-Way ANOVA (Analysis of Variance) to produce a one-way analysis of variance for a quanti-

Table 1. Forest and estimated features of observation plots of ash stands

Observation plots	Latitude & altitude	Tree species composition*	Age years	Stand quality index / stand density index	H [m]	D [cm]	M [m³]
1	48º27'28"N 27º20'56"E 290 m	8Js2Dbs	90	II / 0,70	28	36	330
2	49º06'01"N 28º40'16"E 287 m	4Js5Gb11Jw+Lp+Kl	82	I / 0,70	28	36	307
3	49º06'30"N 28º39'15"E 295 m	4Js5Gb1Jw+Dbs+Lp	91	Iª / 0,90	32	46	400

* Js – *Fraxinus excelsior* L.; Dbs – *Quercus robur* L.; Gb – *Carpinus betulus* L.; Jw – *Acer pseudoplatanus* L.; Lp – *Tilia cordata* Mill.;
Kl – *Acer platanoides* L.; +– <5%/ defined as <5%, H – average tree height, D – average tree diameter, M – timber volume perhectar
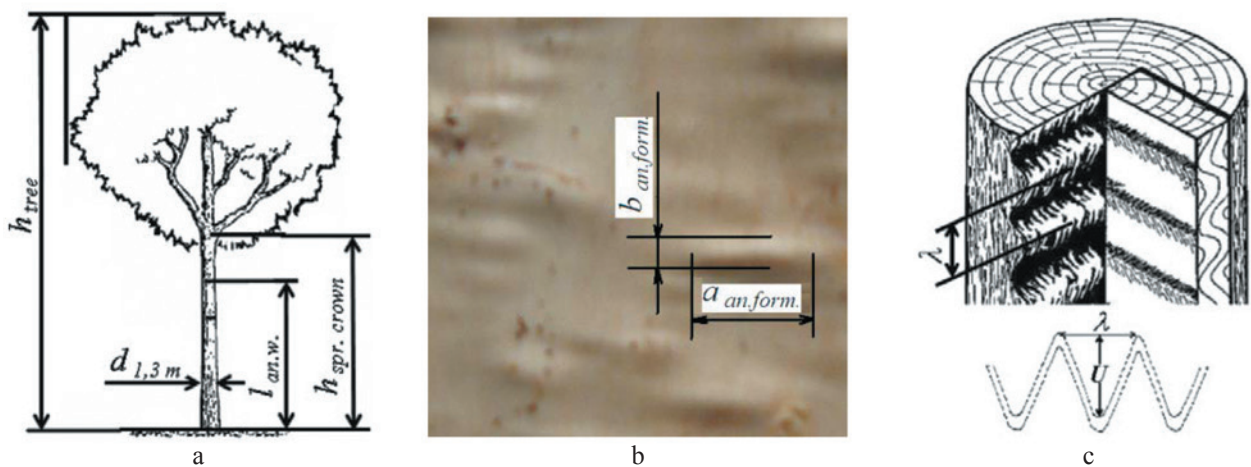

Figure 2. Biometric features of common ash: a) tree ($l_{rn.w.}$ – length of wood anomaly, m; h_{tree} – height of tree, m; $h_{spr.\,crown}$ – spring of crown, m; $d_{1.3m}$ – diameter at the breast height, cm); b) anomally-accentuated wood grains of trunk ($a_{an.form.}$ – width and $b_{an.form.}$ – height of anomaly wood formation, mm; c) curly grain (λ – length of wave, mm; U – amplitude of wave, mm)

tative dependent variable by a single factor (independent) variable. *T*-test was applied for the analysis of variance which analyses the difference in means of a continuous variable between two groups. Null hypothesis has no difference in the mean values and the alternative hypothesis has a difference in the mean values (significant at p≤0,05) (Janssen, Laatz 2007).

3. Results and discussion

Morphological characteristics of trees and the wood density are the best diagnostic features of timber and wood quality (Yatsenko-Khmelevskyy 1954; Zobelet al. 1995; Grześkiewicz 2007; Vintoniv et

al. 2007; Hemery et al. 2008; Sopushynskyy 2012). They are mainly influenced by genetic and environmental factors (Yatsenko-Khmelevskyy 1954; Zobel et al. 1995). The genetics of hereditary variation of ash is well characterised by straight-grained and wavy-grained wood, and reflected by biometric distinctions of trees (Table 2).

Morphological distinctions of wavy-grained ash wood of the age range from 80 to 92 years are characterised by 8–16% bigger diameters at the breast height for ash trees with straight-grained wood. The spring of crown of curly ash started at the average height of 12 m and the length of anomaly wood is in range around 1,1 m. There are no significant changes

Table 2. Biometric features of curly ash with wavy-grained wood with straight-grained wood (in the brackets)

Observation plots	Tree model	Age [years]	h_{tree} [m]	$d_{1,3m}$ [cm]	$h_{spr.crown}$ [m]	$l_{rn.w.}$ [m]	$V_{an.wood}$ [m³]
1	1	90	31,0 (28,0)	42 (38)	11 (20)	1,8	0,22
	2	92	27,0 (27,0)	42 (32)	12 (19)	0,9	0,09
	3	89	28,0 (27,0)	46 (36)	9 (18)	0,5	0,04
	4	92	28,5 (28,0)	45 (36)	8 (19)	1,0	0,12
	5	90	27,5 (27,0)	44 (36)	10 (17)	1,5	0,19
2	6	85	28,0 (28,0)	38 (32)	14 (18)	0,5	0,03
	7	80	27,0 (27,0)	44 (38)	15 (17)	1,8	0,23
	8	83	29,0 (28,0)	46 (38)	10 (16)	2,1	0,29
3	9	91	32,0 (31,0)	44 (40)	15 (19)	0,5	0,03
	10	90	30,0 (29,5)	42 (38)	14 (18)	0,9	0,09
	11	92	31,0 (30,0)	48 (44)	12 (17)	0,8	0,11

Symbols as in Fig. 2.
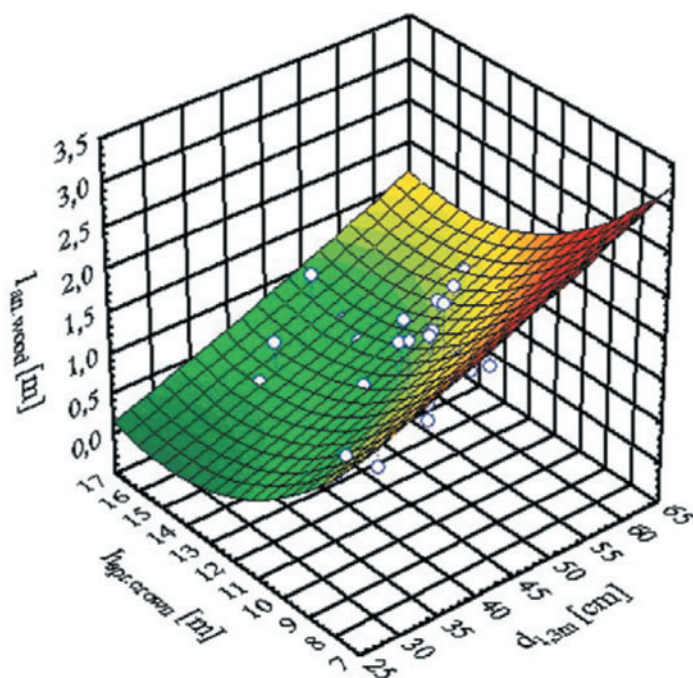
Figure 3. Regression model of the length of wavy-grain ash wood zone

in the study results for trees in different height. The dendrochronologic study revealed that wavy-grained wood ash started to produce in the age range of 11–20 years old.The differences in variability of mean values of the diameter at the breast height and the spring of crown were evident or significant (p<0,05).

The multivariate analysis encompassed the biometric features of curly cCommon ash and showed the significant relationships (0,05) among the length of decorative wood ($Z=l_{an.wood}$), the height to the first living branch ($Y=h_{spr.\,crown}$) and the diameter at breast height ($X=d_{1,3m}$) (Fig. 3). The non-linear regression analyses of

researched variables gave the function:

$$Z = 5,3 + 0,03X - 0,8Y + 1,0E - 4X^2 - 1,4E - 5XY + 0,03Y^2$$

by multiple R = 0,65.

Aesthetic features of wood play an important role due to their volumetric and fashionable patters. Wave-grained wood appearance in furniture is very important for the customers who are buying it. For measuring the wood attractiveness it is very important to use quantifiable or explicable characteristics of wood macrostructure. The wave-grained wood formations of common ash are evaluated by analysing the texture and figure of the wood surface (Table 3).

Statistic evaluation of the aesthetic macrostructure wood characters indicates the high variation of macro structural variables (Table 2). Thus, the coefficient of variation is in the range of 23 to 36%. Thereby, the length of wave varies from 3,25 to 10,83 mm and its amplitude – from 0,37 to 1,74 mm. The average width and average height of anomaly wood formation are equal 15,89±0,80 mm and 5,00±0,18 mm as well as their average number on 0,1 m² of 30±1,11.

Wood density forms an integral component of tree breeding programs and the main characteristics of wood quality. Since the quality of wood is the result of a long process where genetic dispositions of the tree interact

Table 3. Specific features of wave-grain wood of common ash

Variables	N	min	M±m	max	$V, \%$	$P, \%$
λ [mm]	450	3,25	6,52±0,09	10,83	28,4	1,3
U [mm]	300	0,37	1,06±0,02	1,74	30,6	1,8
$a_{an.form.}$ [mm]	52	7,36	15,89±0,80	33,19	36,1	5,0
$b_{an.form.}$ [mm]	52	2,25	5,00±0,18	8,26	25,8	3,6
$N_{an.form.}$ / 0,1 m²	40	15	30±1,11	41	23,3	3,7

N – number of samples; min – minimum; $M\pm m$ – mean ± standard deviation; max – maximum; V – coefficient of variation; P – accuracy figure

Table 4. Annual ring width and wood density of common ash

Variables	Slope of wood grain	N	min	$M \pm m$	max	$V, \%$	$P, \%$
$S_{tree rings}$ [mm]	wavy-grain	49	3,5	5,1±0,17	8,2	23,2	3,3
	0–9º	36	2,8	3,8±0,11	5,1	17,9	3,0
	10–25º	14	2,9	3,9±0,10	4,3	9,2	2,5
	26–45º	21	3,0	3,8±0,11	4,8	13,2	2,9
ρ_6 [kg·m⁻³]	wavy-grain	49	555	581±5,03	635	6,1	0,9
	0–9º	71	457	511±4,29	575	7,1	0,8
	10–25º	14	477	550±7,36	583	5,0	1,3
	26–45º	21	545	567±5,20	585	4,2	0,9
ρ_0 [kg·m⁻³]	wavy-grain	49	634	675±3,18	745	3,3	0,5
	0–9º	107	525	593±3,43	671	6,0	0,6
	10–25º	28	557	640±5,68	675	4,7	0,9
	26–45º	42	635	659±1,57	681	1,5	0,2

ρ_6–basic wood density (oven dry weight of wood / green volume of wood)
ρ_0–the density of oven-dry wood (over dry weight of wood / oven dry volume of wood)

with environmental requirements, the tree growth rate affects not only the formation of wood but also its physical properties (Yatsenko-Khmelevskyy 1954; Zobel et al. 1995; Vintoniv et al. 2007; Grześkiewicz 2007; Hemery et al. 2008). To study the influence of wood fiber orientation on wood density of common ash (Table 4) all wood specimens were grouped depend on the slope of wood fibers: a – wave-grained; b – 0°–9°; c –10°–25°; d – 26°–45°(Sopushynskyy 2011).

The wave-grained wood of Common ash is showing the greater annual rings width (5,1 mm). Assuming the value obtained for wave-grained wood is 100% then the comparison to the value obtained for straight-grained wood indicates clearly that this macrostructure has a lower average annual ring width of 25% (Table 4).

Coefficients of variation of wood density are ranged from 0,9 to 7,1% and also they indicate the statistical significance of the research results. As it was shown in the Table 4, the wood density of ash increases with the rise of the slope of wood fibers. Thus, the average basic wood density with slope of wood fibers 0–9° appears to be the lowest (511 kg·m^{-3}). The density of wavy-grained wood is more than straight-grained wood on 82 kg·m^{-3} in the oven-dry condition and on 70 kg·m^{-3} in the basic condition. Theresearch results show that the slope of wood fiber has a strong effect on wood density of common ash. The differences in variability of mean values of the annual ring width and wood density between wave-grained and straight-grained wood were evident and significant (p<0,05).

Above mentioned specific diagnostic features of wave-grained ash wood take an important place in the young diagnose and breeding of ash trees as well as care for them. Hypothetically, one could argue about the genetic inheritance of this trait. Ash trees with wavy-grained wood deserve special attention in the context of their selection and plantation cultivation. A prerequisite for successful cultivation and conservation of Common ash with wave-grained wood is the study of the nature of its origin, development and monitoring growing trees and woodlands.

4. Conclusions

The results showed that the fresh broadleaves ash forest stands growing in Vinnytsya and Sokyryany regions of Ukraine are characterised by high forest potential on the ash trees with wave-grained wood. The dendrochronologic analysisrevealed that wavy-grained wood ash stars being produced at the age around 11–20 years old. The biometric characteristics such as diameter at the breast height and spring of crown between ash trees with wavy-grained and ash trees with straight-grained wood differ significantly.

Statistic evaluation of the aesthetic macrostructure wood characters indicates that the length of wave varies from 3,25 to 10,83 mm and its amplitude – from 0,37 to 1,74 mm. The average width and average height of anomaly wood formation was equal 15,89 mm and 5,00 mm as well as their average number in 0,1 m^2 was 30. Average annual ring width of wave-grained ash wood was clearly greater by 25% than in straight-grained wood. The relationships among the length of decorative wood (Z=l$_{an.wood}$), the height to the first living branch (Y=h$_{spr.crown}$) and the diameter at breast height (X=d$_{1,3m}$) described by the non-linear regression function $Z = 5,3 + 0,03X - 0,8Y + 1,0E - 4X^2 - 1,4E - 5XY + 0,03Y^2$ by multiple R=0,65.

The density parameter of wavy-grained wood is bigger than in straight-grained wood by 82 kg·m^{-3} in the oven-dry condition and by 70 kg·m^{-3} in the basic condition. The research results show that the slope of wood fiber has a strong effect on wood density of common ash. The differences in variability of mean values of the annual ring width and wood density between wave-grained and straight-grained wood were evident and significant (p<0,05). The identification and production of high decorative timber is one of the important economic and strategic directions for the sustainable forestry and wood processing. Common ash with wavy-grained wood is valuable decorative material for veneer production.

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